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EFFECTS OF ACUTE SLEEP LOSS ON PERFORMANCE,(U)
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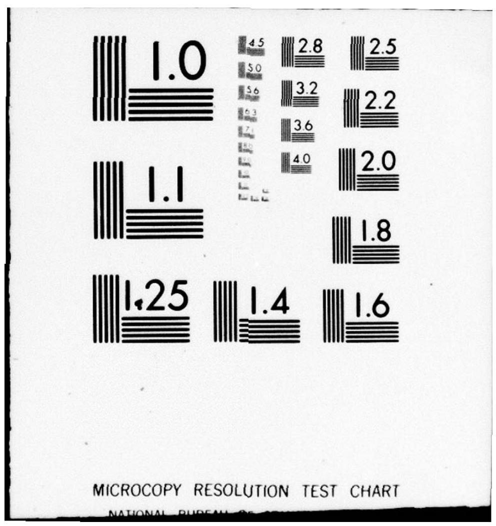
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(11) 8 Jan 1958

Psychology Dept
WRAIR, WRAMC
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(6) # Effects of Acute Sleep Loss on Performance[1]

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I. Introduction

The purpose of this talk is to discuss some general concepts which have developed from experiments on sleep loss. When, in 1956, the Neuropsychiatry Division decided to study sleep loss, the Clinical and Social Psychology Department saw, as a major purpose of the study, the development of general principles which would allow us, on the one hand, to evaluate any test for its sensitivity to sleep loss, and on the other hand, to construct tests that would have desired degrees of resistance or sensitivity to sleep loss.

A preliminary review of the literature revealed some rather disconcerting statements. For example, Ax states that there "is little agreement concerning the psychological and physiological effects produced by sleep deprivation" (1957, Quantitative Effects of Sleep Deprivation). In the Handbook of human engineering data (1955), Tufts College, we find "subjective attitude is the only factor seriously affected by sleep loss." In our review of the literature no test was found which had consistently been shown to deteriorate under sleep loss.

[1] Talk given to Neuropsychiatry Division.

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Of course experimenters in this field have tried to isolate and identify those factors which determine sensitivity of tests to drowsiness, but, unfortunately, few have been able to carry out crucial experiments. A brief historical review will show how certain general concepts did grow out of the experiments on sleep loss. Primary attention will be paid to those concepts which are stated at the psychological level; however, their neurophysiological base cannot be entirely disregarded. Experiments on chronic sleep loss will not be discussed since this introduces additional complications.

II. Brief Historical Survey

The first extensive experiment on acute sleep deprivation in humans appears to be that of Patrick and Gilbert in 1896. They kept three Ss awake continually for about 90 hours, and used a variety of physiological and psychological tests such as reaction time, pain threshold, visual acuity, memory for nonsense syllables, tapping rate, adding, pulse rate, temperature, etc.

They concluded that performance on most of the psychological tests deteriorated with sleep loss. However, their results were irregular and a great deal of fluctuation occurred. We have performed some tests of significance on their data and found borderline results. Patrick and Gilbert made little attempt to generalize their findings.

The next extensive experiment occurred some 30 years later in 1922. Robinson and Herman (1922) kept three Ss awake some 65 hours and tested them on strength of grip, speed of tapping, aiming, naming letters, and

mental multiplication. Their main conclusions were that "the results of the tests were not affected by the insomnia in any marked or consistent manner." Robinson and Herman seem to be the first experimenters to state explicitly that moderate sleep loss will cause little or no loss of efficiency on some tasks. The only general concept they use to explain their results is that of "increased effort," i.e., the Ss put out an extra amount of effort to compensate for any decrement due to sleep loss.

Robinson did another experiment to check these results. (Robinson and Richardson-Robinson, 1922.) The Army Alpha Intelligence Test was given to 25 experimentals and 39 controls. The experimentals stayed awake only one night (about 27 hours' sleep loss). All Ss improved considerably in scores on the Alpha test, the experimentals just as much as the controls. However, the self-ratings of effort showed that the experimentals felt that they had expended considerably more effort than the controls. So Robinson concluded, as he had in his previous experiment, that the major explanatory variable was the amount of effort made by the S.

Nathaniel Kleitman started his sleep loss experiments in 1923 and has continued this work until the present time. He has evolved three explanatory principles. Basic to Kleitman's evolutionary theory of sleep (Kleitman, 1939) is Hughlings Jackson's doctrine of levels of the nervous system. Kleitman states that the most outstanding and significant findings in all studies on lack of sleep point to a fatigue of the higher levels of the cerebral cortex; i.e., he would expect that complex mental activity would be most sensitive to sleep loss.

Confounded with this, however, is a sleep-wakefulness cycle, that is,

"a diurnal variation in the state of the nervous system which determines the degree of mental fatigability..." (Kleitman, 1939, p. 226). To Kleitman, body temperature, performance and fatigability are all synchronous.

Task duration is a supplementary factor. Kleitman states that "mental and muscular performance... can be maintained at normal levels if the tests are of short duration; but sustained effort is impossible." (1939, p. 320)

Muscular activity is mentioned briefly by Kleitman as tending to keep the S awake and alert.

Weiskotten (1925) after a 62-hour experiment on himself, concluded that moderate sleep loss has little effect on accuracy, and the chief loss is in the "power of concentration." Several years later (Weiskotten and Ferguson, 1930) using three Es and two Cs, he ascertained the effect of 66 hours of sleep loss on learning. In general, he ascribed deterioration not to a decline in basic skill, but "an ability to fix attention for a period." He found that "ball-tossing," a well-learned motor task, was unaffected by sleep loss.

Laslett (1924, 1928) performed several sleep-loss experiments and concluded that task duration and task complexity were important factors. In passing he notes that during sleep "the muscles operate though consciousness is not alert." He and Weiskotten seem to be the first to mention that automatic motor sequences are relatively unaffected by sleep loss.

About this time the concept of blocks or performance lapses become

important in fatigue research. A. G. Bills (1931) noted that they were prominent in fatigue curves of mental work. He found that the frequency of blocks increased with fatigue and that errors tended to occur in conjunction with these blocks. After extensive work on the lapses (1935a, 1935b, 1937) he concluded that they were involuntary rest periods.

Warren and Clark (1937) decided to test the notion that sleep loss, like fatigue, caused blocking in mental work. During 65 hours of sleep loss, all four Es showed a distinct increase in the number of blocks on mental arithmetic and color-naming, but no increase in the number of blocks during tapping. The four control Ss maintained constant frequency of blocks through the sleep loss period. For both experimentals and controls, errors tended to occur in conjunction with blocks. It is interesting to note that there was no apparent relation of errors on mental arithmetic and color-naming to hours of sleep loss. This agrees with Weiskotten's results.

Bjerner (1949) studied the effect of sleep deprivation on the blocks that occurred during a complex serial reaction time test. He concluded that the essential difference between a rested S and sleep-deprived S was that these drops or lapses were very brief periods of sleep. Bjerner showed that the lapses were strongly associated with alpha depression on the EEG, and slowing of pulse rate.

Carmichael, Kennedy and Mead (1949) in summarizing the World War II work at Tufts College on fatigue and sleep loss, also noted that the basic pattern was that of periodic blocks rather than continuous decrement. These lapses increased in number and duration with hours of sleep loss.

They believed that these lapses were particularly prominent in continuous, monotonous tasks, because of the motivation conflict produced by such tasks.

A very recent study of sleep loss, an unpublished study by Ax (1957) takes as fundamental that motivation is the chief determinant of performance during sleep loss. His tentative conclusion is that tasks judged to be short, interesting, challenging and highly-motivating will usually show no decrement during sleep loss. The presence of the experimenter is important in determining motivation.

The most recent experiments we know of are those of Wilkinson (1957) at Cambridge. His first exploratory studies led him to use the explanatory concept "level of arousal." He defined low arousal level in terms of tasks with low rate of sensory input, low response rate, no feedback of results, and continuous performance. Wilkinson raised the important question of whether tests which are sensitive to fatigue are also sensitive to sleep loss.

Let us summarize the explanatory concepts noted in this very brief historical survey: It is possible to resist impairment during sleep loss (1) By increased effort (and motivated Ss will usually do this), (2) By raising the "arousal level" of the S (feedback of results, high response rate, etc.), (3) If the task is of short duration, (4) If the task is an automatic motor sequence, (5) If the task does not require fixed attention.

On a somewhat more general level, there is Kleitman's hypothesis that deterioration during sleep loss is an increasing function of the complexity of the mental task and that all performance is modulated by the diurnal temperature-fatigability cycle.

Finally there is the notion that deterioration during sleep loss is a matter of intermittent lapses rather than continuous decrement. By linking alpha depression and pulse rate to these lapses, Bjerner implies that the same neurophysiological mechanism associated with sleep is causing the lapses.

III. The WRAIR Studies

In 1956, when our experiment started we were not fully aware of the explanatory concepts summarized above. In part this was because some of the relevant literature was not available at the time; in part it was the usual difficulty of sifting the grain from the chaff in an area where we had no first-hand experimental experience. The problem as we saw it, was that there was no test that could be relied on to be consistently sensitive to the effects of sleep loss. Accordingly, we set out to survey a wide range of measures in an attempt to locate performance indices which would consistently show impairment as a function of sleep loss.

One of the tests we used was a visual vigilance task devised by Rosvold, Mirsky et al, (1956). Originally designed as a test of brain damage, it was remarkably sensitive to sleep loss. The S sees a series of 31 letters appearing at the rate of about one per second, and he must tap a lever every time an X appears. There are eight X's in the 31 letters. For every S, performance on this test deteriorated steadily and significantly over about 70 hours of sleep loss. The average results are given in Figure 1.

This result was so impressive that we designed an auditory vigilance

test based on the Rosvold-Mirsky test, and using the same set of 31 letters. This test, also, showed significant deterioration, although it was not quite as sensitive as the Rosvold-Mirsky visual test. The results are shown in Figure 2.

These results as well as others, we felt, directly confirmed the findings of Wilkinson and Carmichael: that continuous tasks with low response frequency, low complexity and little feedback would be most sensitive to sleep loss. Accordingly, for the 1957 study, we developed a visual vigilance task with two forms: Form R was designed to be resistant to sleep loss, and Form S, sensitive to sleep loss. In Form R there was a circular tape with 57 letters on it, presented at the rate of one per second. It was designed so that at the beginning of each ten-minute test session, the tape would start at a different letter, thus making it very difficult for the subject to learn the sequence. Of the 57 letters, 37 were X's, about two-thirds of them, so that if an individual responded correctly he would be pressing the lever about once every one and a half seconds. Feedback on errors was provided by a buzzer and a red light which came on whenever the subject made an error of omission or commission.

The tape for Form S had only six letters on it which appeared at the rate of one every five seconds. During the ten-minute test session, the S saw these six letters 20 times. Two of the six letters were X's, so that a response had to be made once every 15 seconds. There was no feedback of error.

Figure 3 gives the means for Form R, the so-called resistant test, and the means for Form S, the sensitive test. As you see, sleep loss has almost

no effect on the so-called sensitive test. The average rank-order correlation of the means with hours of sleep loss is only .17 which is not at all significant. However, Form R shows considerably and significant deterioration at the end of 48 hours of sleep deprivation. The average rank-order correlation is .83 (significant at the .01 level).

As you can imagine, this result caused us to abandon the generalizations we had made from the 1956 data. We spent the rest of the 1957 study attempting to find and test generalizations that would account for the results. In searching for explanatory concepts, we found that research on fatigue by such people as Bills (1931), Broadbent (1953), and Mackworth (1950), had produced ideas that seemed to be directly transferrable to sleep loss. By interweaving notions about fatigue and sleep loss, we finally arrived at a small number of concepts and rules which seemed to fit most of the results.

We have tried to define these concepts in such a way that they will generate rules for the evaluation and construction of tasks with desired degrees of sensitivity to sleep loss.

In other words, these concepts are stated in such a way that they should be testable. Because we arrived at them only after the 1957 study was finished, we do not have any crucial experiments. However, there is a great deal of relevant evidence from our studies and from others.

There are four major concepts:

<u>Lapses</u>

1. Sleep-deprived Ss show brief intermittent lapses. These lapses increase in frequency and duration as hours of wakefulness increase.

2. Certain factors in a situation tend to alert the S, thus preventing or shortening lapses. This "arousal level" is our most poorly-defined concept.

Some examples of alerting factors would be:

(a) The massive sensory stimulation caused by physical exercise, electric shock, loud noise, adrenergic drugs, etc.

(b) Uncertainty--the amount of information presented by each stimulus. In general, simple tasks have more certainty than complex tasks.

(c) Feedback of information on performance.

(d) Task change: any change in the rule for responding, or in the stimuli presented to the S will tend to alert him.

3. Automatic response sequences are relatively resistant to sleep loss.

4. Diurnal rhythm (many but not all tests are affected by the diurnal cycle). No evidence will be given here, but a very large effect was observed on some of the tests.

Having briefly stated the four basic concepts, let us now apply them to various kinds of performance--vigilance, cognitive, motor, and sensory acuity.

Our discussion of the vigilance tasks will be extensive since this is our field of concentration.

I. Vigilance Tasks

The tasks which we have found to be most sensitive to sleep loss are those usually described as "vigilance" or "watchkeeping." By "vigilance task" we mean any situation in which the S must detect signals and respond in some prescribed manner, and E does not warn S before each signal. The range of signals and responses is usually very limited.

There are a number of parameters which determine the characteristics of a vigilance task. Among these are:

1. Test Duration
2. Signal Duration
3. Pacing
4. Redundancy

Only two of these terms seem to require clarification, pacing and redundancy. A "paced" vigilance task is one in which the S cannot control (1) the time when a signal appears or (2) the duration of the signal. An unpaced vigilance task is one like crossing out all the x's on a page of printing, or turning over a pack of colored cards and naming the colors. The S controls the rate of stimulus presentation.

A "redundant" task is one where the signals are so regular and the sequences of signals so well-learned, that the S is actually just running off an automatic response sequence with little attention being paid to the signals. This is what we think happened to the so-called sensitive visual vigilance task, Form S. The cycle of six stimuli was so simple that it was quickly over-learned and became automatic.

Certain of these parameters; e.g., pacing and signal duration,

determine which aspects of the task will be most sensitive to sleep loss. That is, they determine what kind of score (errors of omission, errors of commission, time, number of problems attempted, etc.), will have the highest correlation with hours of sleep loss.

Consider the paced vigilance task with brief signals. If an individual is having frequent short intermittent lapses of attention then it is likely that from time to time a lapse will coincide with a signal, and an error of omission will result. Occasionally, the S will "wake up," realize that he failed to respond and press the lever quickly in an attempt to "catch up." This will cause an error of commission on the next stimulus. Under these circumstances, errors of omission will be more sensitive than errors of commission.

Since automatic motor sequences are resistant to sleep loss, they can be run off during lapses. During sleep loss, there will be difficulty with tasks that require the automatic motor sequence to be inhibited from time to time. On such tasks errors of commission will be more sensitive than errors of omission. Figure 3 shows this rather clearly.

Task duration appears to play some part. At the beginning of a task the S seems to be aroused and he performs rather well. However, it is difficult to sustain attention for more than a few minutes when S is sleep-deprived.

In Table 2, the X task (pressing a lever when X is seen or heard) seems to show the effect of task duration. The first two minutes always have the lowest rank-order correlation. However, the AX task (pressing the lever only when X is preceded by an A) does not show the expected arousal effect

Table 1

Predicted Relation between Pacing, Signal Duration and

Sleep-Loss Impairment

Task Parameters		
Pacing	Signal Duration	Indices which will be sensitive to sleep loss
Paced	Short	Errors of omission
Paced	Long	Reaction time
Unpaced	Short	Errors of omission or reaction time
Unpaced	Long	Reaction time

during the first two minutes. Possibly this is because it was always preceded by ten minutes of the X task.

Since the arousal effect is so brief, we would not expect the sensitivity of larger time blocks to vary with duration. Figure 6 compares the first ten minutes of a Visual Vigilance X task with the second ten minutes. As you can see, there is no effect of task duration; if anything, the first ten minutes seem more sensitive.

As you will recall from our brief review, motivation was considered to be very important by several investigators, and Ax regarded it as the chief determiner of performance. During the 1957 study, two experiments on motivation were carried out, one by Crampton and one by Williams and Gieseking.

Crampton designed a tactual version of the Rosvold-Mirsky vigilance task, in which vibrations (60 cycles per second) were delivered at one per

Table 2

The Effect of Task Duration on the Rank-Correlation of Errors of Omission with Hours of Sleep Loss

	Task Durations in Blocks of Two Minutes							
Test Test	Form	Year	N	1-2	3-4	5-6	7-8	9-10
Rosvold-Mirsky CPT	X	1956	5 Es	.20	.70*	.90*	.90*	.80*
Auditory Vigilance	X	1956	6 Es	.17	.25	.83*	.75*	.75*
Auditory Vigilance	X	1957	10 Es	.50*	.85*	.80*	.80*	.75*
Rosvold-Mirsky CPT	AX	1956	5 Es	.60*	.90*	.80*	.80*	.60*
Auditory Vigilance	AX	1956	6 Es	.67*	.50	.42	.57*	.57*

*Significant at the .05 level or better

second to the face, hands, and knees. S was instructed to release a key whenever he felt a vibration on his right forehead or left hand.

Two levels of motivation were used: high and low. The high-motivation situation was characterized by (1) instructions which emphasized the military importance of the task, (2) partial knowledge of results, (3) exhortation by the E to better one's score, and (4) constant supervision by E (S was brusquely aroused if the slightest sign of drowsiness appeared).

In the low-motivation condition, instructions pertained only to the task, no exhortations or knowledge of results were given by the E, and E remained out of the room as much as possible, arousing S only when it was clear that S was sleeping.

It seems clear from the figure that motivation does make a difference.

However, there were only three pairs in each treatment group and the difference between high and low motivation is not statistically significant.

Williams and Gieseking applied two levels of motivation to the visual vigilance task. These were not differentiated quite so sharply as in Crampton's experiments. The high-motivation Ss were given complete feedback on their performance and were encouraged to compete with others as well as themselves. There was an electric counter in the room which made a loud click whenever a stimulus was presented, the click accompanying a signal could be reliably distinguished from the other clicks.

The low-motivation Ss were given no feedback, and were not exhorted by the E. The counter was removed from the room.

The results are inconclusive. The figure shows that the low motivation Ss appear to be more affected at about 76 hours of sleep loss, but this is not a significant difference. Only five pairs were used in each group, and the correlation with sleep loss is not significant in either group.

It is difficult to generalize about motivation, it is such a poorly-defined variable and so few experiments have been done. However, we feel that "knowledge of results" as such probably increases resistance to sleep loss. Some preliminary results from Wilkinson seem to support this.

Let us now consider the effect of sleep loss on a reaction time tests. If there is a vigilance task in which the signals are of long or infinite duration, neither errors of omission nor errors of commission are likely to occur. Provided that the stimulus duration is longer than the lapse, S will respond correctly. However, reaction time will be affected. A

reaction time test then is somewhat like a vigilance task with infinite signal duration.

What are the effects of sleep loss on reaction time? Figure 9 shows the effect of sleep loss on a two-choice reaction-time test. The slowing in reaction time is significant, whether the mean or median is used, but the mean appears to increase faster than the median.

The lapse hypothesis implies that during sleep loss, there would be some trials on which reaction-times would be as short as the best trials in the baseline period, and some trials where reaction times would be longer than any baseline performance. Gradual impairment (the obvious alternative to the lapse concept) would imply a constant increase in all reaction times during sleep loss. The lapse hypothesis predicts little or no change in the short reaction times, but a disproportionate increase in the long reaction times.

Figure 10 illustrates a test of this idea. Out of the 72 trials during each session for each S the ten longest and ten shortest reaction times were selected. As you can see, the average of the ten longest reaction times increases by almost two seconds during sleep loss, whereas the average of the ten shortest reaction times increases less than one-tenth of a second. This seems to verify the deduction from the lapse hypothesis. However, the increase in the shortest reaction times, small thought it may be, is very consistent and yields an average rank-correlation of .85 with hours of sleep loss, very significant statistically speaking, and a trifle higher than the corresponding coefficient of .72 for the longest reaction times. So there appears to be evidence for both hypotheses,

lapses and gradual impairment.

In 1957 a similar study was done. Figure 11 illustrates the results for a simple reaction time test with 100 trials. The last 50 trials were used for this analysis. Again, the average of the largest reaction times increases significantly with hours of sleep loss (K = .87). Although the change in the shortest reaction times is in the positive direction, it is not significant (K = .37).

The basic concepts have been illustrated by vigilance tasks and it has been shown how such factors as pacing, task duration, motivation, etc., can be used to make a test more or less sensitive to sleep loss.

Can these same concepts be used to explain the effects of sleep loss on cognitive tests?

II. Cognitive Tests

For our purposes we will consider that cognition covers such activities as remembering, imagining, conceiving, judging, reasoning, etc. Cognitive tasks are usually constructed so that sensory and motor processes cause little variation.

Let us talk about cognition very briefly.

The effect of lapses on a cognitive task will depend primarily on whether it is paced or unpaced. Between lapses we assume that the S will function on about the same cognitive level as usual. Therefore, if allowed enough time, he will be able to maintain his previous level of correct reasoning, correct calculation, etc. Because of the lapses, however, he will take more time. So in an unpaced cognitive task (which is by far the

more common type) we would expect speed to decline with sleep loss, but accuracy to remain almost constant. Later, Dr. Jacqueline Goodnow will present evidence for this deduction from her own work as well as that of previous experimenters.

III. Sensory Acuity

Sensory thresholds are usually determined under conditions where the S is alerted just before the stimulus is presented. We believe that the likelihood of a lapse is very low immediately after the S has been alerted. Putting this together with our belief that the S's abilities show little impairment between lapses, the deduction is that no changes will be found in threshold values. In the 1956 study, Dr. Robert Butler found no change in pitch threshold.

In general, there is no evidence in the literature for changes in sensory thresholds with two possible exceptions: pain and taste. There are contradictory findings on pain; Schumacher, Goodell, and Hardy (1940) claim that there is no variation with sleep loss, whereas Kleitman (1939, p. 706) reports lowered threshold. Only one experiment has been done on taste (Furchgott, 1956). Thresholds for salt and sweet remained the same, but the threshold for sour taste increased.

IV. Motor Tasks

Although there are a few contradictory findings, the majority of Es have reported no change in simple motor tasks like tapping, strength of grip, simple ball-tossing, etc. There is a great deal of anecdotal evidence which suggests that automatic motor sequences can be performed even

when the S is extremely drowsy. In our 1957 study Thaler and Loveland used a "speed of tapping" test and found no change.

It is difficult to make deductions about perceptual-motor tasks such as rifle marksmanship, tracking, aiming steadiness, etc. In general, we would expect that as the task became more of a vigilance task, it would behave accordingly. Thus if a marksmanship test were paced, we would expect accuracy to decline.

Figure 12 shows that, in the only perceptual-motor task we had, aiming accuracy, per cent of hits declined more rapidly than speed. It is not clear why number of attempts drops precipitously after 50 hours of sleep loss. Our concepts do not seem to cover adequately this kind of test.

V. Physiological Variables

Thus far our explanatory principles have been on a psychological level. However, some of the most striking effects of sleep loss are on physiological variables. Dr. Edward J. Murray found a relation between amount of sleep loss and decline in oral temperature. Dr. John Armington found a sharp decline of alpha amplitude with sleep loss.

Figure 13 shows an analysis which attempts to relate performance directly to alpha amplitude. The four kinds of responses the S could make on the auditory vigilance test have been measured for the alpha amplitude which accompanies each.

Obviously, alpha declines as a function of sleep loss, no matter which behavior is being measured. But the lowest alpha amplitude at each stage of sleep loss always accompanies errors of omission. Since the lapse

hypothesis states that errors and lapses should occur synchronously, the implication is that lapses are somehow synchronized with alpha depressions. This is not the first time such a relation has been found. In 1949 Bjerner predicted the effect from the lapse hypothesis, and found it in a serial reaction time test. That brief depressions in alpha amplitude accompany falling asleep has been known to clinical electroencephalographers for some time, and this was described in detail in 1938 by Davis and his colleagues. Their Ss were instructed to signal every time they had a spell of drowsiness. These brief sleeps were almost invariably preceded by an alpha depression.

V. Conclusion

It is clear then, that to the extent that sleep loss results can be accounted for by the lapse hypothesis, they can be explained in terms of the neurophysiological mechanisms which modulate the electrical activity of the cortex.

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